COMPTON POLARIMETRY

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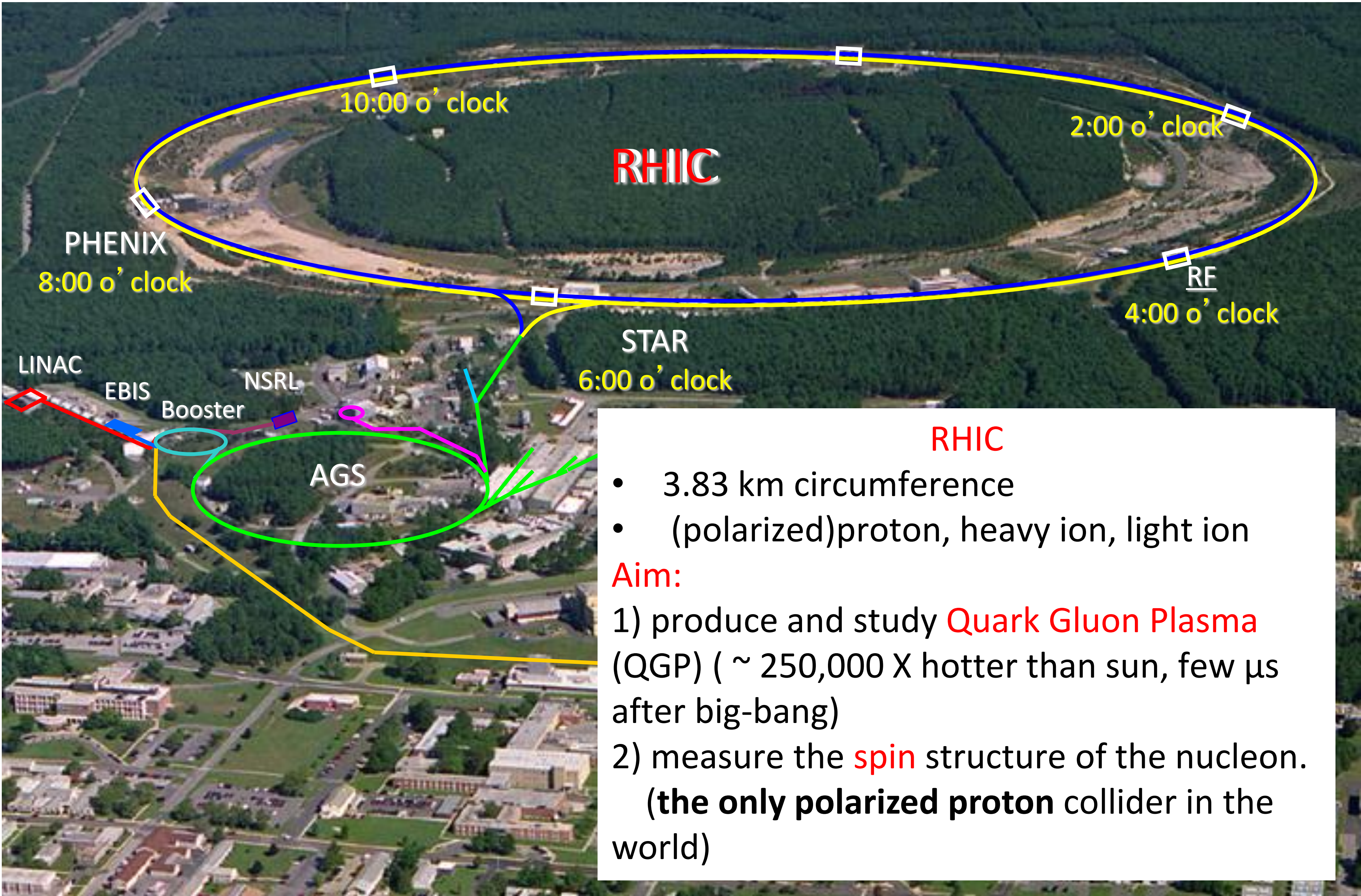
Laser Applications to Accelerators

Outline

- RHIC
- Basis for Compton polarimetry
- Kinematics
- Compton Asymmetry
- polarization of the electron
- Summary

The Relativistic Heavy Ion Collider (RHIC)



RHIC

- 3.83 km circumference
- (polarized)proton, heavy ion, light ion

Aim:

1) produce and study Quark Gluon Plasma (QGP) (~ 250,000 X hotter than sun, few μs after big-bang)

2) measure the spin structure of the nucleon. (**the only polarized proton** collider in the world)

Basis for Compton polarimetry

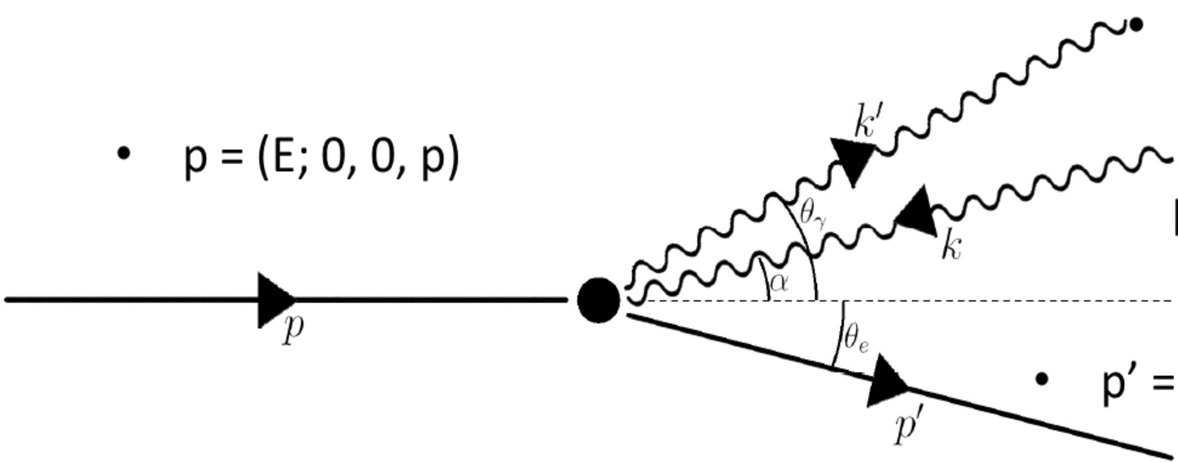
- The scattering of a photon off an electron

- The cross section for this interaction depends on the relative alignment of the spins of the two interacting particles

Kinematics

- Individual electrons, moving along the z-axis with an energy E,
  $p = (E; 0, 0, p)$
- incoming photon, denoted by $k = (k;- k \sin\alpha, 0, -k \cos\alpha)$, where α is the angle of the incoming photon with respect to the beam axis.
- The photon source is a high-power **green laser**.
- The electron imparts some of its energy to the photon, and is deflected from the main beam line by an angle θ_e
- The recoil electron thus has 4-momentum $p' = (E'; -p' \sin\theta_e, 0, p' \cos\theta_e)$.
- The photon scatters at an angle θ_γ ; $K' = (k'; k' \sin\theta_\gamma, 0, k' \cos \theta_\gamma)$

- $p = (E; 0, 0, p)$



- $K' = (k'; k' \sin\theta_\gamma, 0, k' \cos \theta_\gamma$

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- $p' = (E'; -p' \sin\theta_e, 0, p' \cos\theta_e)$

Applying conservation of 4-momentum,

$$p^{\mu} + k^{\mu} = p'^{\mu} + k'^{\mu}$$

- The energy of the scattered photon can be found in terms of the incident photon and electron parameters as;

$$k' = k \frac{E + p\cos\alpha}{E + k - p\cos\theta_{\gamma} + k\cos(\theta_{\gamma} - \alpha)},$$

- The energy of the recoil electron is;

$$E' = E + k - k'$$

Compton Asymmetry

- The theoretical longitudinal asymmetry, A_l, for the Compton scattering of electrons and photons with spins parallel, σ+, and spins anti-parallel, σ−, is given by

$$A_\ell = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \ ,$$

The experimentally measured asymmetry, A_{exp}

$$A_{exp} = \frac{n^+ - n^-}{n^+ + n^-}$$

n^+ is the number of Compton scattering events with electron and photon spins parallel, and

n^- with the spins anti-parallel.

- The experimentally measured asymmetry A_{exp} is related to the theoretical asymmetry A_l through the polarizations of the electron beam, P_e, and the scattering photons in the laser beam P_γ, by

$$A_{exp} = \frac{n^+ - n^-}{n^+ + n^-} = P_e P_\gamma A_\ell \ ,$$

- The longitudinal polarization of the electron beam is therefore

$$P_e = \frac{A_{exp}}{P_\gamma A_\ell} \ ,$$

Compton scattering from proton (RHIC)

- The cross-section for Compton scattering from protons is small.
- smaller than the analogous electron cross section by a factor of $(m_e/m_p)^3$
- Modern lasers, with their high power densities and pulse energies, stand a chance of making up this difference in rate.

Summary

- Given the polarization of laser (P_γ) the polarization of the electron beam (P_e) can be measured by
  - Calculating the cross section (theoretical) ➔ A_l
  - counting the number of Compton events (experimental) ➔ A_{exp}

$$P_e = \frac{A_{exp}}{P_\gamma A_\ell} \ ,$$

Reference: Compton Polarimetry; Douglas W. Storey (The Qweak experiment, at Thomas Jefferson National Accelerator Facility)

LASER COMPTON POLARIMETRY OF PROTON BEAMS
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Backup

The Compton scattering cross section

- $$\rho = k'/k \cong \frac{4\gamma^2}{1 + \frac{4k\gamma}{m_e} + \theta_\gamma^2\gamma^2} = \frac{4a\gamma^2}{1 + a\theta_\gamma^2\gamma^2} ,$$

$$a = \frac{1}{1 + \frac{4k\gamma}{m_e}} .$$

$$\frac{d\sigma}{d\rho} = 2\pi r_0^2 a \left[\frac{\rho^2(1-a)^2}{1-\rho(1-a)} + 1 + \left(\frac{1-\rho(1+a)}{1-\rho(1-a)} \right)^2 \right]$$

$$A_\ell = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} ,$$

$$A_\ell = \frac{2\pi r_0^2 a}{\frac{d\sigma}{d\rho}} (1 - \rho(1+a)) \left(1 - \frac{1}{(1-\rho(1-a))^2} \right) .$$